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EFFECTS OF FULL SPECTRUM LIGHTING IN SUBMARINES

by

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Naval Medical Research and Development Command
Research Work Unit M0100.001-1023

Released by:

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SUMMARY PAGE

PROBLEM

To determine if "full spectrum" lighting aboard submarines prevents the decline in vitamin D levels and improves the mood and well-being of the crew.

FINDINGS

There was no evidence that lights which mimic the spectral distribution of the sun prevented the decline of vitamin D levels in the blood. The subjects rated their health as being better under full-spectrum light, but this was not accompanied by higher ratings of mood or quality of sleep. There were no differences in the way the ratings changed during the patrol under the two lights. It was, however, difficult to interpret the data, and further research is needed.

APPLICATION

These findings are relevant to the question of which lights should be used aboard submarines.

ADMINISTRATIVE INFORMATION

This investigation was conducted as part of Naval Medical Research and Development Command Work Unit M0100.001-1023 - "Enhanced visual performance on submarines." It was submitted for review on 12 December 1986, approved for publication on 9 April 1987, and has been designated as Naval Submarine Medical Research Laboratory Report No. 1092.

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Abstract

Crewmen on a nuclear submarine were monitored during two patrols, one during which the submarine was lighted with standard fluorescent lights and a second during which it was equipped with "full spectrum" lights whose spectral distribution is much more similar to sunlight and emit a greater amount of high energy ultraviolet light. The levels of 25-OH vitamin D in their blood was measured at the start and during the sixth week of each patrol. In addition, the men kept daily logs during the patrols noting such things as their health and mood. There was no evidence that the full spectrum lights prevent the typical decline of vitamin D levels in the blood during a patrol. However, the initial levels of vitamin D in the blood were quite different, because the two patrols began at different times of the year, making it difficult to interpret the results. The men preferred the full-spectrum light and rated their health as being better under this light, but this was not accompanied by higher ratings of mood or quality of sleep.

INTRODUCTION

It is now clear that exposure to sunlight is vital for health (Wurtman, 1975; Wurtman, et al, 1985). Light affects, either directly or indirectly, a number of physiological and behavioral functions. It has long been realized that lack of sunlight can lead to a vitamin D deficiency. This affects calcium metabolism (Davies, 1985) and may lead to rickets (Loomis, 1970). Vitamin D deficiencies can still be found among the elderly in the northern United States (Neer, 1985) and must be due to insufficient exposure to sunlight (Holick, 1985).

Light also indirectly affects such neuroendocrine organs as the reproductive system (Thorpe, 1968; Wurtman and Weisel, 1969; Gilman and Fischer, 1971), adrenal cortex (Leeman et al 1962), thyroid (Reiter and Faschini, 1969), and pineal gland (Reiter, 1985).

The effects of light on the circadian rhythms are marked (Wurtman et al, 1985), and there is now clear evidence of effects on the light-sensitive membranes in the rods and cones of the eye (Young, 1978).

Of most interest, perhaps, are the reports that light affects various behaviors, including activity level (Spalding et al 1969; Ott, 1965, 1968, 1973), aggression, eating and drinking (Zucker, 1971), reproduction (Thorpe, 1967), emotionality (Mos et al, 1973), as well as mood, sleep, and reaction-time (Lieberman et al, 1985).

The effects produced by light on physiological and behavioral responses depend, naturally, on its intensity and the length of exposure. But they also depend in some cases on the spectral distribution of the light. It is the high energy ultraviolet (UVA) component of sunlight which promotes the synthesis of vitamin D in the skin. This in turn affects calcium absorption and thus the state of the bones (Neer, 1985). The spectral distribution of sunlight varies to some extent with the season and the time of day (Henderson, 1970); there is appreciably less UV in the winter than in the summer for higher latitudes. But far greater variations in the spectral distribution of light are found with artificial lights. These typically diverge greatly from that of sunlight and are often deficient in UVA radiation (Thorington, 1985).

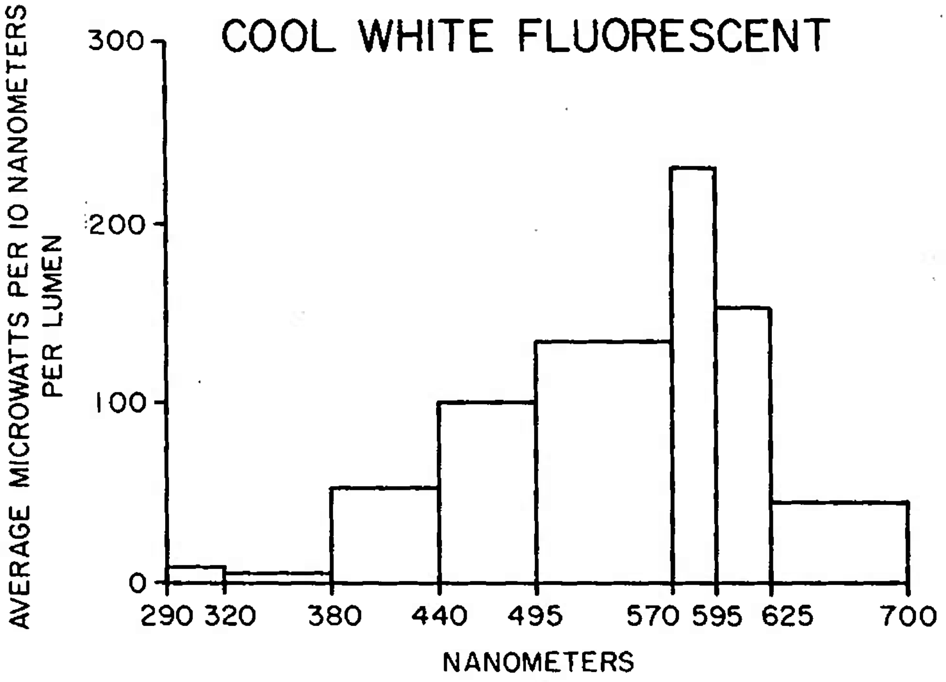
These factors are important for those individuals who spend long periods of time in artificial light. The most dramatic example is that of men on submarines, who may spend weeks without seeing natural light. Schlichting (1986) has found significant reductions in the vitamin D levels of submariners during patrols. It has been shown that the calcium metabolism of these men is disturbed (Davies and Morris, 1974, 1979; Davies et al, 1975), and that this can be attributed to lack of exposure to sunlight-- or, perhaps more accurately, to lack of exposure to UV radiation (Davies, 1985).

The question then arises, can these undesirable effects be avoided or alleviated by providing such individuals with artificial light with an UV component and which more closely resembles the spectral distribution of natural sunlight? Ott (1964, 1973) and Lieberman et al (1985), for example, have reported improvements in human performance when this was done. What is not clear is how long the exposure time and how bright the artificial light must be. Holick (1985) has found that vitamin D synthesis in the skin of a white man exposed to sunlight at the equator reaches a plateau after about 15 minutes. (With black skin, about two hours of sunlight may be required.) The intensity of artificial light does not, of course, begin to compare with that of equatorial sunlight. This study sought to determine if exposing submariners to "full spectrum" artificial light arrested the decline in their vitamin D levels (Schlichting, 1986; Davies, 1985) and had any effect on psychological factors.

METHOD

Subjects

One of the crews of a ballistic missile submarine agreed to participate in the study for two successive patrols. Twelve officers and enlisted men volunteered to give blood samples and to keep logs of their health and mood, while another eight agreed to keep the logs but not to give blood. Of these, ten gave blood during the first patrol, and eight in the second patrol; 18 men continued the entries in the log books during the first patrol, and 12 men kept them up for the second patrol.



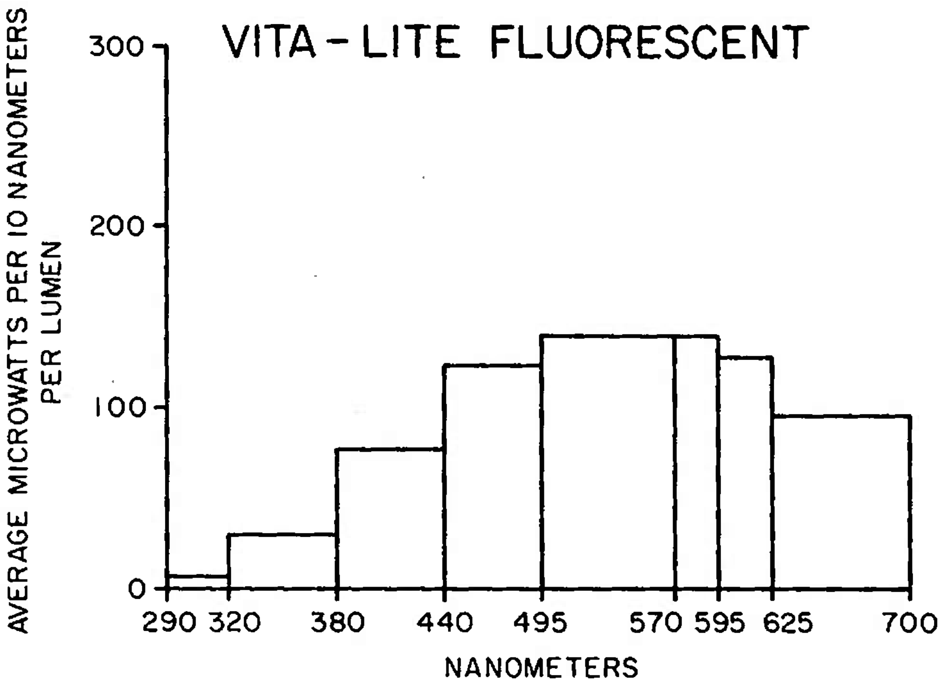


Figure 1. Spectral distribution of standard "cool white" fluorescent lights and "full spectrum" lights.

Lights

The submarine was lighted by standard "cool white" fluorescent tubes which emit relatively little ultraviolet (UVA) radiation. The effects of these lights were compared with those of the UV emitting "Vita-lite" fluorescent tubes manufactured by the Duro-Test Corporation (Figure 1).

The standard bulbs were housed in luminaires with translucent diffusing covers. These did not transmit ultraviolet light, and new covers which did transmit UV were installed with the full spectrum lights (Figure 2). It should be noted that the measurements of the spectral emissions of the lights were made with new bulbs. The extent to which the spectral emission of the bulbs had changed by the end of the patrol is not known; we do not know, for example, how constant the amount of UV emission by the full-spectrum lights remained.

The light levels reflected off white cardboard fastened to the surface of the various dials and work surfaces ranged from about 10 to 70 ft-L. These varied so widely from one duty station to another because of the different distances from a fixture to the work station which it illuminated. A general comparison of the light from the two types of bulbs is illustrated by measurements at one location. With the standard fluorescent tubes and cover it was 18.5 ft-L (63.4 c/m 2), whereas with the full-spectrum light and the UV transmitting cover it was 16 ft-L (54.8 c/m 2). Although the measured intensity was slightly less with the full-spectrum lights, it is interesting that there was general agreement that the full-spectrum light seemed to be much brighter. A difference of this magnitude using the same light source would be imperceptible.

For the experimental test, it was not feasible to exchange all the standard lights for the full-spectrum lights. They were substituted for the standard lights only in locations in which the subjects would spend time every day. Thus the ward-room, the crew's mess, the lounge, and the library were fitted with full-spectrum lights. And since a machinist, a radioman, and five electricians were among the volunteers, so were the maneuvering room and the radio shack.

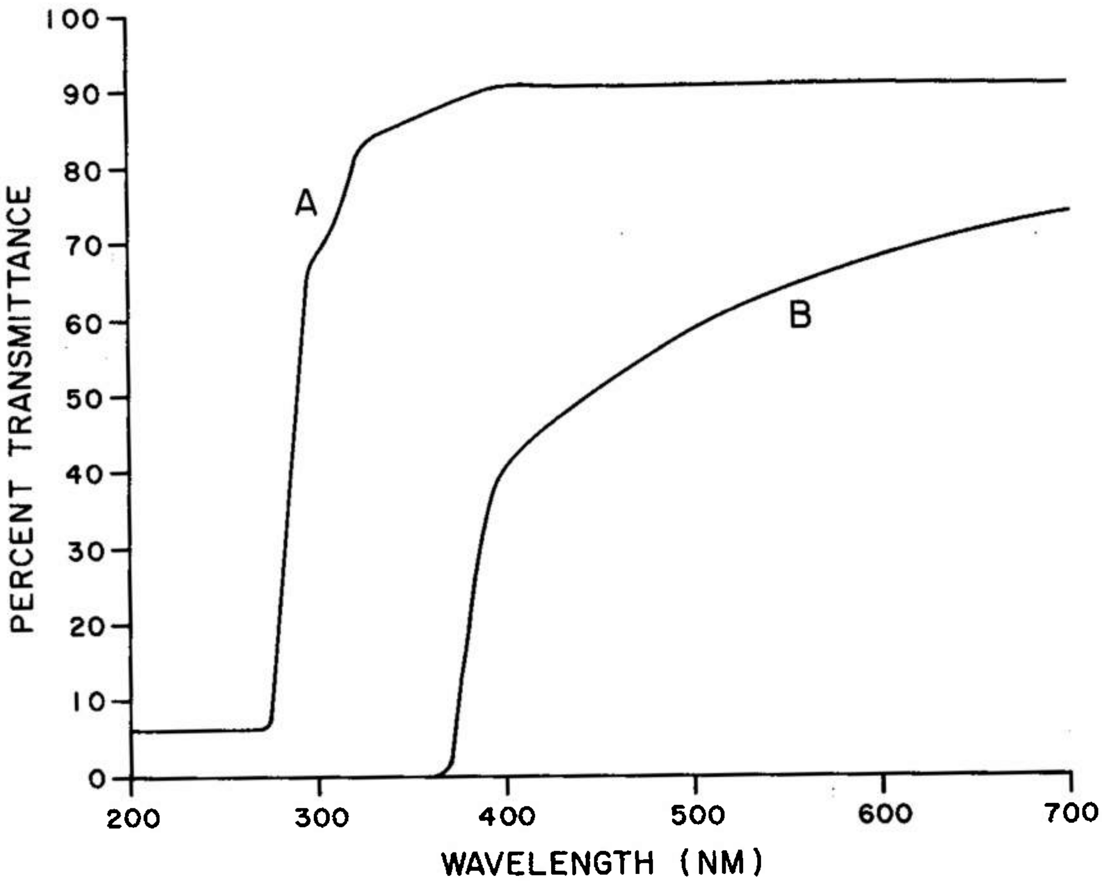


Figure 2. The percent transmittance at each wavelength of a standard fluorescent light behind a standard cover (B) and a full spectrum light behind a UV-transmitting plastic cover (A).

Daily Logs

Each subject was given a 3x5 inch notebook, inscribed with each day of the patrol, and with spaces in which he was to enter the answers to these questions each day.

1. Rate your health from 1 to 10
   (1 = very sick; 10 = healthy)

2. Rate your mood from 1 to 10
   (1 = out of sorts; 10 = happy)

3. Rate how you slept last night
   (1 = badly; 10= very well)

4. How many cups of coffee, tea, and caffeinated soda?

5. How many cigarettes?

6. How many aspirin pills?

7. How many servings of milk and ice-cream

8. Vitamin pills?

9. Any other medicine?

Procedure

Measurements were taken during two successive patrols by the same crew. The first patrol began at the end of the summer; the second patrol began at the beginning of the winter. The submarine was lighted by the standard fluorescent tubes during the first patrol and by the full-spectrum tubes during the second.

Blood samples were taken at the start of each patrol and again during the sixth week of the patrol. Each subject had a 7 ml sample of blood drawn by antecubital venipuncture. A 2 cc aliquot of this serum was immediately centrifuged and frozen for analysis at the end of the patrol.

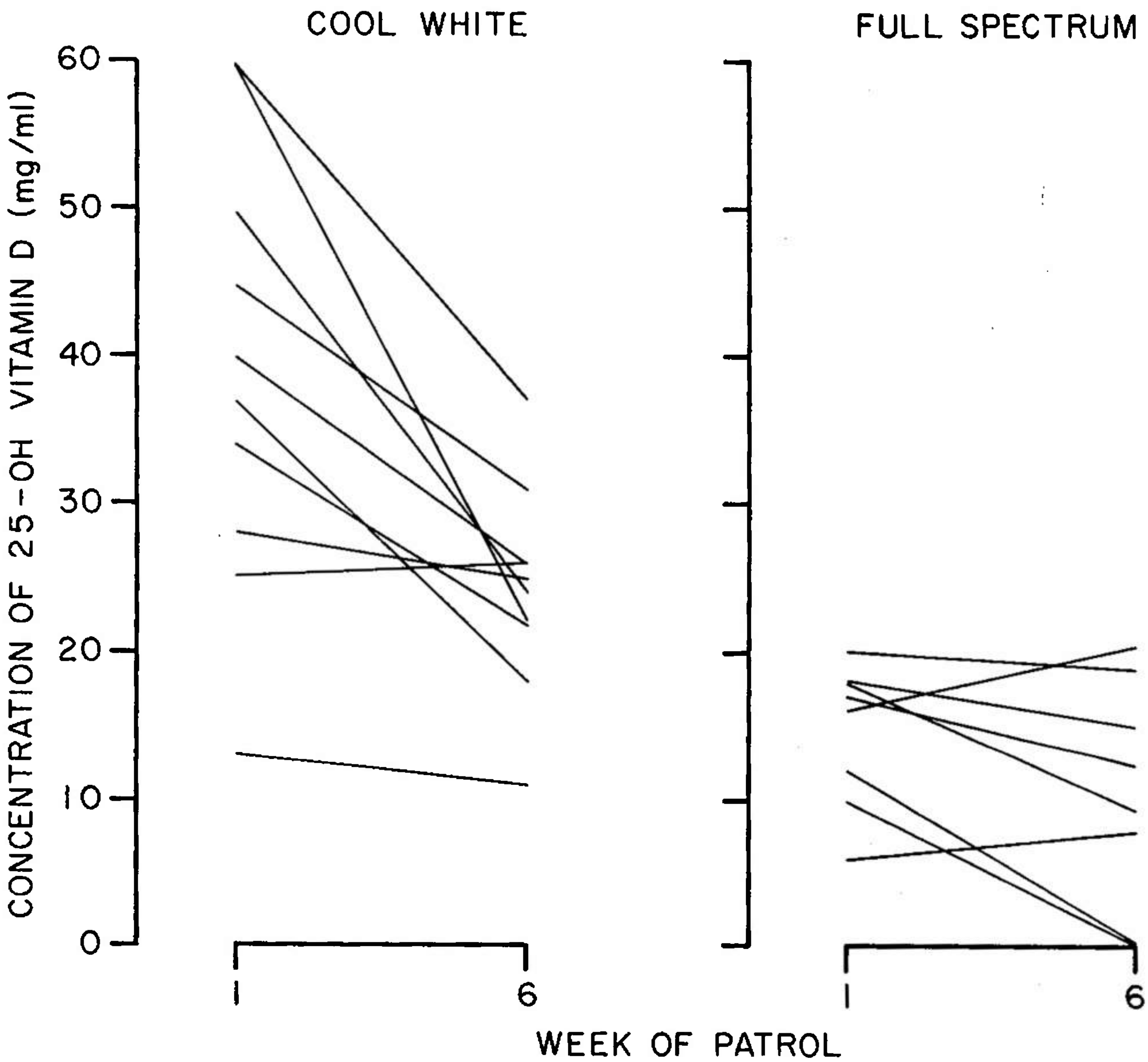


Figure 3. The concentration of 25-OH vitamin D in the blood samples at the beginning and during the sixth week of each patrol under standard fluorescent light (left) and under full-spectrum light (right).

RESULTS

The subjects' vitamin D status was assessed by measuring the concentration of 25-hydroxy vitamin D in the blood samples. Figure 3 gives these values for the 10 subjects in the first patrol and the eight subjects in the second patrol. The mean 25-OH-D level at the start of the first patrol was 39.2 mg/ml, and under the standard lights this declined to 24.0 mg/ml. Only one of the men did not show a decline in 25-OH-D level during the first six weeks of the patrol. The decline was highly significant ($p < .01$), according to the Wilcoxon Matched-Pairs Signed-Ranks Test.

The mean 25-OH-D level at the start of the second patrol was 14.62 mg/ml, and this declined to 10.75 mg/ml by the sixth week. Two men had no measurable levels at the end of the six weeks. On the other hand, two men showed no decline at the end of six weeks. The two mean values were not significantly different, according to the Wilcoxon test.

The entries in the log books for each subject were averaged for each week. Figure 4 shows the mean ratings for mood, health, and quality of sleep, and the number of caffeinated drinks and aspirin tablets per day. As is evident from Figure 4, the first patrol was terminated after seven weeks, whereas the second one continued for 10 weeks. Each set of ratings was subjected to two analyses. First, the significance of the differences between the ratings assigned during each patrol were tested using the Mann-Whitney U test. Second, the significance of the changes in the ratings during a given patrol was tested using a one-way repeated-measures analysis of variance.

The Mann-Whitney U test showed that the subjects rated their health as being significantly better ($U=6$; $p < .05$) under the full-spectrum lights. In addition, their consumption of caffeinated drinks was very significantly lower ($U=0$; $p < .001$) under the full-spectrum lights. Mood, sleep, and consumption of aspirin was not significantly different during the two patrols, although the latter was less under full-spectrum lights until the seventh week of the patrol.

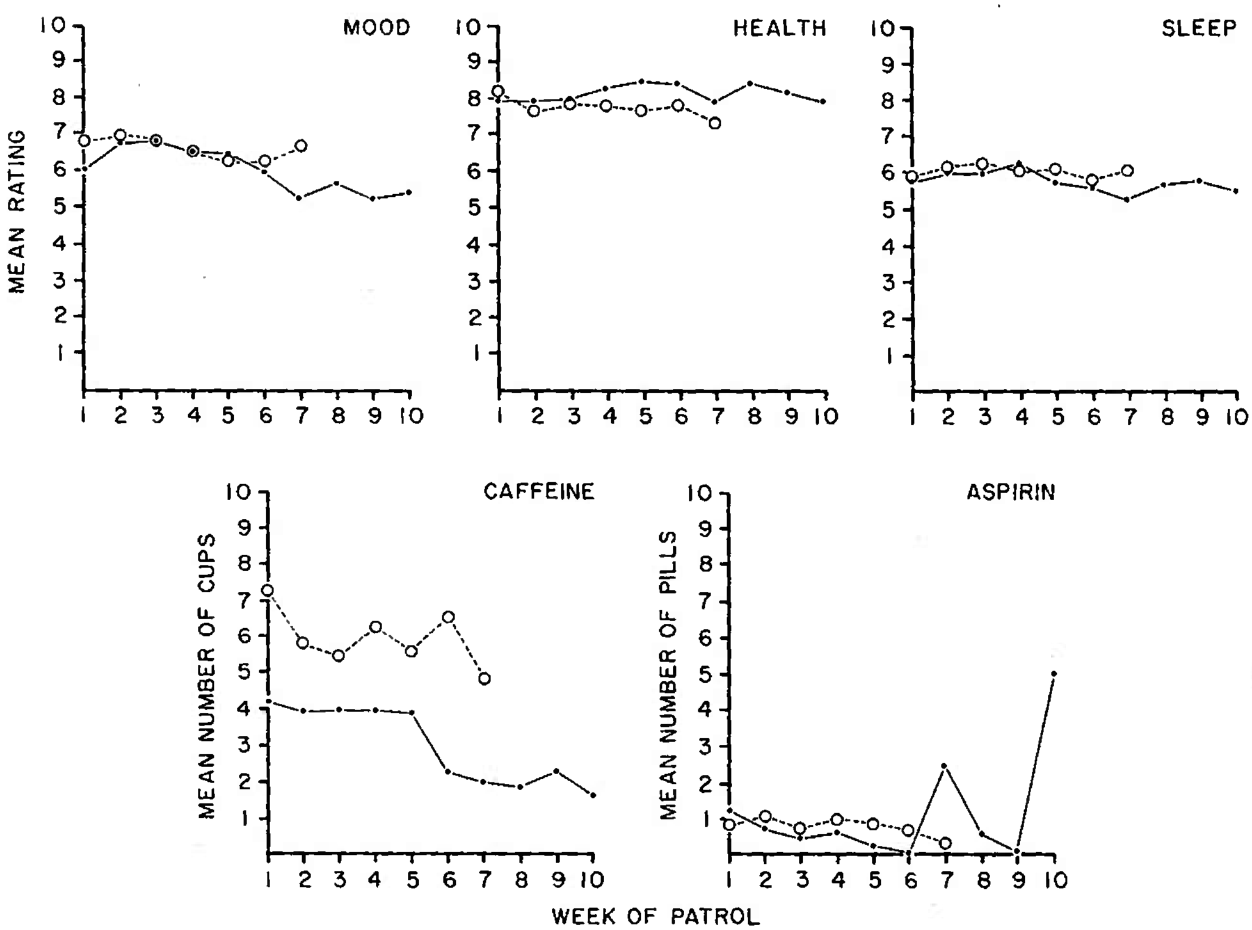


Figure 4. Self-ratings (1 = poor; 10 = [illegible]) for mood, health, quality of sleep, and the number of caffeinated drinks and aspirin tablets averaged for each week under standard light (open circles) and under full-spectrum light (filled circles).

The analyses of variance showed that with the standard lights, the subjects were, in every case, very significantly different from each other, but the only significant change in the ratings during the course of the patrol was that the consumption of caffeinated drinks declined ($F(6,96)= 2.07$, $p < .05$). There were no significant changes in mood, health, sleep, or consumption of aspirin under the standard lights.

With the full-spectrum lights, the consumption of caffeinated drinks again declined significantly during the patrol ($F(9,63)= 3.52$, $p < .01$). But none of the other ratings changed significantly during the patrol. It should be noted, however, that the decline in the mood ratings was almost significant ($F(9,99)= 1.86$, $p < .10$). Once again, the subjects were significantly different from each other on all the variables.

The use of vitamin pills and medicines was too small for analysis.

DISCUSSION

The levels of 25-OH vitamin D in the men exposed to the full-spectrum light did not increase, but it is not completely clear whether or not these lights are effective in arresting the decline of vitamin D that occurs during a submarine patrol. On the one hand, the mean decline was not significant and was of a smaller magnitude than it was under the standard fluorescent lights; on the other hand, eight of the 10 men who gave blood showed a decline, and two of them had no measurable levels of 25-OH vitamin D at all after six weeks on patrol.

The interpretation of the results is made very difficult by the fact that the two patrols started at different times of the year. The first began at the end of the summer. The crew no doubt had spent time in the sun and began the patrol with high levels of 25-OH vitamin D. The second patrol began in November, and the initial vitamin D levels were much lower. It may be that the drop in 25-OH vitamin D levels was not significant, because the subjects' initial levels were so low to begin with that it was difficult for further losses to occur. Figure 3 shows that the amount of reduction in the vitamin D levels was much less for those subjects whose initial levels were relatively low. This raises doubts that the smaller reductions under the full-spectrum lights were caused by these lights. It may be noted in passing that it was originally intended to carry this study through at least four patrols (and perhaps eight), but this did not prove to be feasible.

It should also be noted that since only selected compartments were illuminated with the full-spectrum lights, it is impossible to quantify the degree of exposure for each subject.

The self-ratings of health were significantly better during the patrol under full-spectrum light. The perception of better health was not accompanied, however, by reports of better mood or better quality of sleep. Indeed, it was under the full-spectrum light that the decline in the ratings of mood almost reached significance. This was no doubt due to the men being away from home at the approach of the Christmas holiday. It is doubtful that any kind of lighting could assuage depression under those circumstances. Aside from this, there were no differences in the changes in the ratings under the two lights as the patrols progressed, although it may be noted that the men reported that they preferred the full-spectrum lights

Finally, the subjects reported far less consumption of caffeinated drinks under the full-spectrum light. The reason for this is completely unclear.

Previous work suggests that higher intensities than were used in this study are probably necessary to produce physiological or behavioral changes. In his study of the use of light to treat jet lag, Wever (1985) tested a wide range of intensities. He found that intensities up to about 500 cd/m 2 had no effect on circadian rhythms. He concluded, indeed, that exposure to around 1000 cd/m 2 for 3 hours was necessary to affect circadian rhythms. Lewy et al (1980; 1987) also concluded that light of ordinary room intensity does not suppress melatonin, which underlies circadian rhythms, and an intensity of about 800 cd/m 2 is required. This was later confirmed by Rosenthal et al (1985). Kripke (1985) has reported significant improvements in the treatment of depressive and seasonal affective disorders with intensities of 500 cd/m 2 but had much less success with dimmer lights. Czeisler et al (1986) also found ordinary room light to be much less effective than bright light, although it has been suggested that even dim light falling on the face may have some effect (Sinclair, 1987).

It might be possible to produce high intensities of UVA light on submarines-- perhaps, for example, in the shower rooms, where, moreover, more skin would be exposed. But if this were done, then the problem of health effects must be considered. There is no question that short wavelength radiation can cause injury (Sperling, 1980; Diffey, 1980). There is now evidence that even the relatively dim fluorescent lights pose a danger to health (Sykes, et al, 1981; Cole, et al, 1985) at least for some, if not all, individuals (Harber et al, 1985).

In summary, the concept of full-spectrum lighting is intriguing, but the use on submarines of artificial light emitting appreciable quantities of UV radiation must await definitive research on both its beneficial effects and the potential hazards.

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Crewmen on a nuclear submarine were monitored during two patrols, one during which the submarine was lighted with standard flourescent lights and a second during which it was equipped with "full spectrum" lights whose spectral distribution is much more similar to sunlight and emit a greater amount of high energy ultraviolet light. The levels of 25-OH vitamin D in their blood was measured at the start and during the sixth week of each patrol. In addition, the men kept daily logs during the patrols noting such things as their health and mood. There was no evidence that the full spectrum lights

prevent the typical decline of vitamin D levels in the blood during a patrol. However, the initial levels of vitamin D in the blood were quite different, because the two patrols began at different times of the year, making it difficult to interpret the results. The men preferred the full-spectrum light and rated their health as being better under this light, but this was not accompanied by higher ratings of mood or quality of sleep.